and will continue to be, the chiefly important method of sociology; and assuredly, in the course of time, it will bring our knowledge of society up to standards of thoroughness and precision comparable with the results attained by any natural science.

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*RECENT ADVANCES IN THE ANALYSIS OF THE EARTH'S PERMANENT MAGNETIC FIELD.**

THE 'earth is a great magnet' and as such is subject to the same laws which pertain to any other magnet—these are facts established by the experience of over four centuries. How and whence the earth has received its magnetism are questions we can not as yet answer, nor, in my opinion, shall we be able to answer them definitely until we have solved the problems as to the causes of the *variations* of the earth's magnetism. I firmly believe that when we have discovered the causes of the periodic and aperiodic variations, such as the diurnal variation, annual variation, secular variation and magnetic perturbations, we shall have strong hints given us as to the *origin* of the earth's magnetism. It is through the study of the *variations*, then, that we hope some day to be able to attack the problem as to the origin with some degree of success. Until this study has been completed, it is not believed that anything more than mere surmises, such as the magnetic literature contains *in quanto* can be given.

Whether the earth is a magnet like a lodestone or an electromagnet, is another question which can not as yet be definitely answered, though there are various indications that the earth's magnetization partakes of the character of both. Here again the definitive answer depends upon the successful solution of the questions as to the variations of the earth's magnetism both as to time and space.

These introductory paragraphs are intended to emphasize the proposition that if progress is to be made in the subject of the earth's magnetism, we must first make a careful and exhaustive study of the facts which are daily experiences, before attempting broad, theoretical generalizations based on more or less inadequate data permitting at the most mere qualitative tests of the deductions of theory. What are needed are the facts for *quantitative* tests. Even then, it will be found, in some instances, that more than one theory will satisfactorily explain the same facts and that a final decision must be left to future generations. However, the *facts* will remain as a permanent acquisition. *The accumulation of clean-cut facts regarding the earth's magnetism is the great task of the present generation.*

In the hope of enlisting interest in this comparatively unexplored field of scientific inquiry, it will be my endeavor to reveal some of the gaps to be filled as well as to exhibit those facts considered as safely established. It must be remembered that we are working in a field bordering on several other sciences, such as astrophysics, geophysics, geology and meteorology, so that he who wishes to become an expert must have at his command the ability to make the best and most intelligent use of the experimental facts of several of the older, recognized sciences. The physicist now-a-days has no time to attempt to master so special and comprehensive a subject as that of the earth's magnetism, with its manifold ramifications into cognate sciences, for he finds it sufficiently difficult to keep in touch with the rapid advances in his own subject. However, if the physi-

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cist, the mathematician, the geologist or the astrophysicist has presented to him the problems of the earth's magnetism concerning him specially, definite advance along certain lines may be confidently expected. The point then made is that the successful solution of some of the vexing problems of the earth's magnetism, in this day of rapid advances in experimental research, can not be attempted by one individual; he must associate with him experts in several of the older, fundamental sciences and have at his command a staff of computers. It must, hence, be a source of great gratification that this dream has been realized in the establishment by the Carnegie Institution of a Department of International Research in Terrestrial Magnetism, with facilities for adequately and exhaustively collecting, collating, supplementing and discussing magnetic data. With such means, let us hope that before very long we may be able to present a more favorable report on the state of our knowledge regarding the earth's magnetism, than the one which can be given now.

One of the most fundamental inquiries to be made in the discussion of any of the earth's magnetic phenomena, before attempting a theoretical explanation, is as to the *seat* of the forces giving rise to the phenomenon in question. Thus many a theorist might have saved himself some pains had he first addressed himself to this inquiry. To illustrate:

Suppose our first question to be the following: Since we can produce the magnetic phenomena pertaining to the earth's so-called 'permanent' magnetism, observed on the surface, by a system of closed electric currents, where are these currents? Do they circulate around the earth below the surface or in the regions above us? We know, as a fact of common experience, that the end of the needle designated as the north-seeking end, or for short, the north end, points approximately towards the north. Hence, applying Ampere's rule, the electric currents necessary to produce this phenomenon must circulate around the earth from east to west, if they be *inside* the earth, and if they are, on the other hand, *outside* the earth, they must circulate from west to east. To determine where the currents really are we must resort to another well-known phenomenon, viz., that the end of the needle which points to the north dips below the horizon in our hemisphere and points above the horizon in the southern magnetic hemisphere. Applying to this phenomenon Ampere's rule, we shall find that the currents can only circulate from east to west, hence combining this deduction with our previous one, the answer is that the electric currents which are capable of producing the observed magnetic phenomena cited circulate from east to west inside the earth.

Now this is a perfectly simple and obvious application of a fundamental law in electromagnetism, and yet for want of this test many eminent investigators have lost valuable time and even to-day some cases of transgression or omission might be cited. Thus some of the theories of the secular variation suppose that the electric currents causing this variation are situated chiefly outside of the earth. However, according to recent calculations, as based virtually upon the mathematical application of Ampere's rule, it is found that the observed facts can be made to harmonize best with a system of forces situated chiefly inside the earth. [Since the reading of this paper, the calculations reveal the existence of also a minor system of outside currents taking part in the production of the observed secular variation.]

The first one to make a mathematical test of the seat of the earth's magnetic forces, coupled also with an analysis into

spherical harmonic terms to the fourth order, was Gauss, from whose time a new era in magnetic science was ushered in. As the result of his mathematical analysis, it was definitely proved that by far the greatest portion of the earth's permanent magnetism is to be referred to a system of forces inside the earth and, furthermore, that this system possesses a potential. There were thus deduced two great fundamental facts of nature that outweigh in importance all of the speculative theories concerning the 'how and whence' of the earth's magnetism.

Gauss's calculations have been repeated several times with the aid of more complete material by several analysts, one of them being the noted astronomer and mathematician, John Couch Adams; Gauss's deductions have been verified by all of them.

The most elaborate analysis and attempt at perfection of the theory embodied in the Gaussian analysis was that for 1885 by Professor Adolf Schmidt, at present in charge of the Potsdam Magnetic Observatory in succession to the late and lamented Professor Eschenhagen. Schmidt made provision in his equations: (*a*) For the effect of the spheroidal figure of the earth, Gauss having taken a spherical figure, (*b*) for a possible effect due to forces whose seat was outside the earth, and (*c*) for a possible effect not to be referred to an inside or outside potential, but to a system of vertical electric currents passing through the earth's surface, whether from inside or outside.

Schmidt found that about 95 per cent. of the total magnetization of the earth was to be referred to an inside potential and that the remainder was due to a small outside potential and an electric current system traversing the earth perpendicularly to its surface. [The writer has since found that the principal term of the outside potential is displaced about one hundred degrees (100°) to the *west* with reference to the principal term of the inside potential.]

Fritsche in the main verified Schmidt's work, though he did not introduce the refinement due to taking into account the spheroidal figure of the earth, but retained the simpler equations based on the spherical figure.

The writer has recently made a critical comparison of the results thus far obtained by the various analysts, and has derived the differences between the elements as computed upon the basis of the theory and the observed or chart quantities, his purpose being to ascertain wherein further improvement of the theory is needed and what direction promises the best success. The residuals exceed many times the errors of observation.

It would appear that at the present stage very little increased accuracy has been gained by taking into account the spheroidal figure of the earth and that the theory must receive elaboration in other fundamental directions. Thus, for example, suppose the principal portion of the earth's magnetic system to be situated at some considerable depth below the surface—a condition of which we in fact have indications—then the question must be considered as to the effect arising from the magnetic permeabilities of the strata intervening between the seat of the system and the place of measurement of the forces. Instead of having the simple Laplacian equation and, as the result of which, a strictly harmonic distribution of the forces, we may have instead the more generalized equation:

$$\frac{\partial}{\partial x}\left(\mu\frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial V}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial V}{\partial z}\right)=0,$$

and in consequence a quasi-harmonic distribution. So that the Gaussian potential expression, based on the simple Laplacian equation, may represent only a first approximation to the truth.

The material for testing this hypothesis, however, is not yet either at hand or sufficiently complete.

And right here we must record a most lamentable condition of our knowledge regarding the general distribution of the earth's magnetic forces. One of the surprising results of my critical comparison, above referred to, was the fact that *the accuracy in the determination of the earth's magnetic potential is about the same whether we use the magnetic charts of Sabine of 1840–5 or the best modern magnetic charts.* In other words, whereas magnetic surveys have steadily progressed on land areas and even have been repeated in certain instances in greater detail, the magnetic survey of the great oceanic areas and of the unexplored land regions has made very little progress during the past half century. The advent of the iron ship has materially lessened the yield of useful magnetic data and the expeditions designed for securing sea results have been unfortunately too few and far between. In the Antarctic regions, for example, practically no progress had been made since the observations of Ross in the *Erebus* and *Terror* during the fourth decade of the last century until the recent Antarctic expeditions of the British and German empires.

Fortunately, however, there is an awakening interest in this direction. Thus a committee has been appointed by the International Association of Academies, at its recent meeting in London, to consider methods for securing increased accuracy in magnetic work at sea. Furthermore, the plans of the Department of Terrestrial Magnetism of the Carnegie Institution embrace cooperation in the magnetic survey of the oceanic areas, and it is confidently hoped that a beginning in this direction can soon be made. Instruments for this purpose have already been ordered. Also, I am glad to be able to announce that, having succeeded in organizing the detailed magnetic survey of the land area of our country, attention has next been paid to inaugurating similar work at sea on the Coast and Geodetic Survey vessels; three of them have already been fully equipped for this purpose and this fall two more will receive their magnetic equipments. While these vessels can only obtain magnetic data incidentally in the course of their surveying work, experience has shown that a very satisfactory degree of accuracy can be secured by their skilled officers. The magnetic declination and dip can be obtained, for example, to about 5′ to 10′ and the total force to about one five-hundredth part.

We next inquire, *is the earth's magnetic energy increasing or decreasing?* This is a question of fundamental importance to theories of the earth's magnetism. As is well known, the earth's magnetic elements are subject to a secular variation whereby considerable changes are produced in the course of time. A secular variation may result from a change in the intensity of the magnetization of the earth, or from a change of the direction of magnetization, or from both causes.

The first term of the Gaussian potential is of a simple harmonic type and constitutes by far the largest term; it represents about 65 to 70 per cent. of the total magnetization and can be physically interpreted as a uniform or homogeneous magnetization symmetrical about a diameter, inclined $11\frac{1}{2}°$ to the earth's axis of rotation. This diameter Gauss defined as the earth's magnetic axis, with respect to which he determined the magnetic moment due to the first term. Tabulating the values of the magnetic moment as derived for different epochs from the various analyses, we shall find that it has decreased in forty-six years by 1.6 per cent.—an alarming loss, if true!

The question now is, whether this apparent loss is in any way wholly or partially compensated for by a possible increase in magnetic energy of the portion of the earth's magnetism represented by the remaining terms of the Gaussian potential, *i. e.*, by the portion which can not be referred to a uniform magnetization about some diameter? If mutual compensation does not take place, what is the annual loss of the earth's total magnetization?

To answer this query, I have made use of the well-known function in physics giving the energy W, of a distribution of forces in terms of the field intensity, F, viz.:

$$W=\frac{1}{8\pi}\int\mu F^2 d\tau$$
$$=\frac{1}{8\pi}\int\int\int\mu(X^2+Y^2+Z^2)dxdydz,$$

where μ is the magnetic permeability and $d\tau$ is the element of volume and X, Y, Z are the rectangular components of F. The integral is confined to the space outside of earth, so that we may take μ as a constant and set it equal to 1. We may also give the expression the following form:

$$W=-\frac{R^2}{8\pi}\int VZds.$$

Here V is the magnetic potential and Z the vertical force on the earth's surface, R the earth's mean radius and ds the element of surface. As a check I have made some of the calculations with both forms and have gotten, of course, identical results.

The following table gives the values of the magnetic energy as derived for the various epochs and as dependent upon the best of the analyses thus far made:

TABLE I. VALUES OF THE EARTH'S TOTAL MAGNETIC ENERGY IN C. G. S. UNITS (ERGS).
(The tabular numbers are to be multiplied by the cube of the Earth's mean radius.)

No.	Computer of Potential.	Epoch.	I.	II.	III.	IV.	II + III + IV.	Total.
1	Erman-Peterson......	1829	.03562	.00026	.00015	.00004	.00045	.03607
3 and 6	Adams..................	1842.5	3590	29	15	3	47	3637
4	Fritsche..................	1842.5	3614	28	14	3	45	3659
8	Adams	1880	3481	36	17	4	57	3538
9	Fritsche.................	1885	3472	34	15	4	53	3525
5 and 11	Neumayer-Petersen..	1885	3464	35	16	4	55	3519
10 and 13	Schmidt......	1885	3494	34	15	4	53	3548
	Mean of first three...	1838	.03589				.00046	.03635
	Mean of last four....	1884	3478				54	3532
	Change in..............	46 years	—.00111				+.00008	—.00103

Hence we have for

	Earth's Total Magnetic Energy.
1838	0.03635 R^3 Ergs
1884	0.03532 R^3 Ergs

or a loss of 0.00103 R^3, or 2.88 per cent., or about one thirty-fifth part in forty-six years. This result is a startling one, for, if true and if the loss in the earth's magnetization continued at the same rate as prevailed during the period 1842–1885, it would imply that the earth will have lost its magnetic energy in about 1,600 years; hence extreme caution should be employed before reaching a definite conclusion. I have made some attempt to ascertain whether this loss can be accounted for by the difference in the material used in the construction of the various charts, and while it would appear that the loss is greater than the effect due to the difference of material, I am unwilling at present to announce a definite conclusion, but think it best to leave this question, at present, open.

Allusion was made above to the *possible*

existence of vertical electric currents passing through the earth's crust, as revealed by Schmidt's analysis. He found that there was on the average for the entire earth, for every square kilometer of surface, a current of one sixth of ampere, passing perpendicularly through the surface, either from the air into the earth or *vice versa.* However, as certain investigators found it difficult to harmonize a current of this strength with the known phenomena of atmospheric electricity, and since similar investigations conducted over well-surveyed, though restricted, areas by several eminent magnetists did not reveal these currents, Schmidt was led to doubt his result and ascribe it to systematic map errors.

The existence of these currents is revealed by the non-vanishing of the line integral of the magnetic force taken around a closed curve on the earth's surface. Such line integrals serve as a test of the hypothesis of a potential, as was first shown and approximately applied by Gauss. Let us choose, as our circuit, a parallel of latitude, and let us call, as is customary, the component of the horizontal magnetic force resolved in a west-east direction, the Y component, then, if $d\lambda$ is the element of the parallel,

$$\int_0^{2\pi} Y d\lambda = 0,$$

if the earth's entire magnetic force is due to a potential. If, on the other hand, electric currents of the kind mentioned exist, then, if I represents the total amount of electricity passing per second of time through the zone from the north geographical pole down to the parallel around which the circuit is made, expressed in electromagnetic units, we have:

$$I = \frac{1}{4\pi} \int_0^{2\pi} Y d\lambda.$$

In a paper published in 1897 I computed the values of I for every fifth parallel from 60° N. to 60° S. as based on Neumayer's magnetic charts for 1885, and also gave a graphical representation along a meridian of the average distribution of the currents found. The resulting system was such a methodical one as to strongly suggest that there might be some truth, after all, in the existence of vertical earth-air electric currents.

With the aid of the facilities of the Department of Terrestrial Magnetism of the Carnegie Institution, I recently have had my calculations for 1885 repeated for two other epochs, viz., first, as based upon Sabine's magnetic charts for 1840–5, which depended upon magnetic data distributed over about seven decades, with the date 1840–5 about in the middle of the series and secondly, as based upon Creak's charts for 1880 issued just after the magnetic results of the *Challenger* expedition were available to him.

A further check upon the computations was obtained by a consideration of the magnetic declination charts alone, viz., for four epochs—Sabine (1840–45), British Admiralty (1858), Creak (1880) and Neumayer (1885). The calculations were based on the following principle: the downward electric currents will deflect the north end of a magnetic needle to the west, whereas the upward currents will deflect the north end to the east. The results obtained thus, agreed well with that obtained from the Y components.

The mean results as derived from all the computations are given in the table on the following page.

For example, through the region of the earth between the parallels 50° north and the equator, the resultant quantity of electricity passing every second of time from the air into the earth amounts to 419×10^4 amperes. In the zone between the two parallels 50° N. and 40° N., the resultant currents are upward and the total amount

TABLE II. VERTICAL EARTH-AIR ELECTRIC CURRENTS.

[Plus sign means upward currents ; whereas minus sign implies downward currents.]

Zone.	I in 10^4 A.	i in A per sq. km.
50 N. to Equator	—419	
40 N. to Equator	—539	
30 N. to Equator	—544	
20 N. to Equator	—313	
10 N. to Equator	— 90	
Equator to 10 S.	+105	
Equator to 20 S.	+203	
Equator to 30 S.	— 9	
Equator to 40 S.	— 86	
50 N. to 40 N.	+120	+.038
40 N. to 30 N.	+ 5	+.001
30 N. to 20 N.	—231	—.057
20 N. to 10 N.	—223	—.052
10 N. to Equator	— 90	—.020
Equator to 10 S.	+105	+.024
10 S. to 20 S	+ 98	+.023
20 S. to 30 S	—212	—.053
30 S. to 40 S	— 77	—.021

of electricity passing per second of time from the earth to the air is 120×10^4 amperes; dividing the latter quantity by the total area of the zone, the upward current is found to average for the zone 40 N. to 50 N., 0.038 ampere per square kilometer. The quantities i in the last column give a maximum downward current in the zones 20 N. to 30 N. and 20 S. to 30 S., and upward currents near the equatorial belts, and again beyond parallels 30°.

The general conclusion to be drawn appears to be:

All of the modern magnetic charts—i. e., since those of Sabine for 1840–5—unite in indicating the probable existence of vertical earth-air electric currents of the average intensity over the region 45° N. to 45° S. of one thirtieth of an ampere per square kilometer of surface. These currents of positive electricity proceed upward (from the earth into the air) near the equatorial regions where there are ascending air currents, and downward near the parallels 25° to 30°, i. e., in the regions of descending air currents. Near the parallels 40° the electric currents are again upward, thus corresponding once more with the general atmospheric circulation. Beyond the parallels 45° the results appear too uncertain to warrant drawing a definite conclusion.

If it be true that the vertical electric currents are to be associated with air currents, and are hence convection currents, the importance of choosing circuits for testing the validity of the potential hypothesis in localities of steady air currents is made manifest. It is thus clear that meteorological conditions may play an important part—as already pointed out in my 1897 paper—in investigations as to the existence of vertical electric currents from magnetic surveys over limited areas.

In order to make some tests as to the manner of distribution of the upward and downward electric currents, the currents over quadrilaterals bounded by two parallels 10° apart and two meridians, likewise 10° apart, have been derived for the entire region from 60° N. to 60° S., for the three epochs 1842, 1880 and 1885. As a general result, it did not appear as though the directions of the electric currents—whether up or down—were to be associated with the distribution of land and water. There was, however, a decided indication, *for each epoch*, that over the areas of low pressure, where the air-currents are upward, there the electric currents were likewise, in general, upward, and that over the areas of high pressure where there are descending air-currents, there the electric currents were likewise descending.

Thus, as the average result, from the three epochs we have:

Region.		Quantity of Electricity
60° N. to 60° S.	for areas of low pressure:	$+829 \times 10^4$ amperes
	" " " high " :	-638×10^4 "

(+ means upward electric currents; —, downward electric currents.)

The average effect of electric currents for the region 45° N. to 45° S. is on the

east-west component of the earth's magnetic force (Y), 0.001 C.G.S. unit, or about one fiftieth of the average value of Y. The average effect on the horizontal intensity is about one one-thousandth part, *i. e.*, on the order of the error of a field determination. However, the average effect on the declination is about 0.2°—about six times the error of a reduced field determination of the declination on land, and about one to two times the error of a determination at sea by the most approved methods.

Having given the results to be deduced from a mathematical analysis of the earth's permanent magnetic field in accordance with the principles laid down by Gauss, let us now briefly turn our attention to another *mode of attack with the purpose of deriving physical interpretations of the various harmonic terms entering into the Gaussian expression.* The general title of the series of the papers devoted to this subject, of which the fourth number appeared in the September issue of the journal *Terrestrial Magnetism and Atmospheric Electricity,* is 'The Physical Decomposition of the Earth's Permanent Magnetic Field.'

The first harmonic finds a ready physical interpretation: it represents that entire portion of the earth's total magnetization which can be referred to a uniform homogeneous magnetization of the earth about a diameter inclined to the axis of rotation. This term represents about 65–70 per cent. of the total field. Let us term it the primary or 'normal' field.

The diameter or axis of magnetization of this field for 1885 made an angle of 11° 25.7′ with the rotation axis and pierced the northern hemisphere in longitude 68° 30.6′ W. of Greenwich. Its magnetic moment was 0.32298 R^3, C.G.S. units, R being the earth's mean radius. These figures were dependent on Schmidt's analysis of the earth's permanent magnetism, and a slight revision would be required in accordance with his latest published Gaussian coefficients. However, as it was found that these slight revisions are on the order of error of determination, it will, therefore, not be worth while at present to make any change.

In No. II. of the series of papers alluded to, it was shown how the determinations of the magnetic axis and of the magnetic moment were dependent upon the portion of the earth considered in the calculations, so that strictly the quantities adopted apply only to the area embraced. Fortunately, however, the effect of the neglected portions of the earth—the polar regions—diminishes rapidly with advancing latitude, so that the values as adopted for the primary field, depending as they did upon data from 60° N. to 60° S., will not differ sufficiently from those obtained, had there been data over the entire globe, to vitiate the general deductions regarding the characteristics of the 'residual' or 'secondary field,' *i. e.*, that portion of the earth's total magnetization remaining after deducting the homogeneous magnetization (the first term).

The map of this residual field has now been constructed for three epochs; first, for 1885 and recently also for 1842 and 1880, the first depending on Neumayer's magnetic charts for 1885, the second on Sabine's charts and the third upon Creak's charts. The maps of the residual field for the first two epochs agree well in all the principal features with the one for 1885.

The residual magnetization can thus be broadly characterized: it consists chiefly of two main magnetizations transverse to the axis of rotation, one system lying in the northern hemisphere, the north end attracting pole (N_1) being east of the south end attracting poles (S_1', S_1''), and the other in the southern hemisphere, the direction of magnetization being the reverse

of the former, the north pole (N_2) lying now west of the south pole (S_2). The poles of the two systems are situated, approximately, near the 40° parallels—this is even true of the tertiary system N_3S_3.

The secondary magnetic equators (the lines along which the residual vertical force is zero) occupy practically the same positions for the three epochs. It is as yet too early to decide as to any probable secular shifting of the positions of the secondary poles. The interval is too short, in view of the meagerness of the data on which the charts depend, to make certain any deductions.

What has thus far been gained by the decomposition of the earth's total magnetic field into a primary and into a secondary one?

In the first place, the residual field clearly exhibits the fact that it is not a heterogeneous one, but, in general, remarkably systematic in its structure. There is, therefore, a very strong indication that it is produced by some distinct physical cause operating in the same general manner over the entire earth. The hope is thus clearly held out that we may still further resolve the residual field, starting with fundamental, physical causes.

My present belief is that the chief physical cause of the residual field is to be referred to the distribution of temperature within the stratum of the earth's crust here concerned.

There is a very remarkable correspondence between the principal features of the residual magnetic field and those exhibited on a chart of isabnormal temperatures. It is found that the earth as a magnet acts like any other magnet as regards application of heat. Thus, wherever the earth's surface is relatively warm, on the average for the year, there the magnetization of the earth shows a decrease, and where, on the other hand, it is relatively cold, there it suffers an increase. The comparison held so far, that it is possible to reproduce the residual magnetic field, in its general characteristics, with the aid of temperature charts.

The criticism has been made that this relation between residual magnetism and temperature distribution may only be an apparent one, since the latter referred to surface conditions, whereas the former pertained to strata at considerable depths below the surface. However, the isabnormal temperatures plotted were based on annual means; hence the effects due to annual variation and diurnal variation were eliminated. I am not aware that any one has given a physical explanation of the situations of the maxima and minima shown on an annual isanomalous temperature chart. Their annual positions are probably largely dependent on the radiation of the internal heat of the earth. We can not say, as yet, at what depth the principal thermal features shown at the surface are eliminated; it is known that the isothermal surfaces in the interior conform with those of the surface to a considerable depth. In any case, there is no question that as land areas are pierced, a steady increase of temperature is encountered. Over oceanic areas, on the other hand, there is at first a decrease until nearly a zero temperature is reached at the ocean beds, and then, presumably, an increase as the penetration continues. So that we shall have temperature gradients along parallels of latitude down to a considerable depth.

I shall not discuss this matter further now, as it is being made the subject of a special examination. Many have surmised that the distortion of the earth's magnetic field is to be attributed to the distribution of land and water; but the problem is to show in what manner the distribution causes the observed effects. The first attempt, as stated, will be to ascertain whether

the cause is to be sought in the distribution of temperature in the upper stratum of the earth's crust, as produced largely by the distribution of land and water. *The results of the decomposition have thus revealed one promising mode of attack of the problem as to the causes of the asymmetrical distribution of the earth's magnetism.*

Another extremely interesting result is that a very close similarity is found to exist between the chart of the residual permanent magnetic field and that of the system of forces causing the diurnal variation of the earth's magnetism. The two magnetic systems are identical in their general characteristics except in one respect, viz., the first is to be referred to a system of magnetic forces in the earth's interior, whereas the second to a system outside, the relative positions of the poles being governed accordingly. Thus at Greenwich mean noon, for example, the north end attracting pole of the first system would be about vertically below the south end attracting pole of the second system, and the south end attracting pole of the first would be about directly below the north end attracting pole of the second system—this statement holds for the main transverse magnetization in each hemisphere.

There appears to be more than a chance connection in this relation, as is shown by the horizontal vector diagrams for various parallels as resulting from the two respective fields.

I have had the impression for some time that the earth's permanent magnetic field may play a very important part in the production of the diurnal variation field as observed on the earth's surface. No satisfactory explanation has as yet been given of the manner in which the peculiar magnetic system of forces causing the diurnal variation is actually produced. Schuster's first attempt at the construction of the equipotential lines of the diurnal variation field, based as it was on exceedingly meager data, was, nevertheless, remarkably correct in its general features, as shown by the recent more elaborate work of Fritsche. We, therefore, have now a fairly accurate map of this field.

The existence of some form of radiation from the sun which does not penetrate to the lowest strata of our atmosphere, and which is yet capable of deflecting magnetic needles on the earth's surface, appears to have been definitely proved by the recent magnetic observations during solar eclipses. It was, furthermore, shown that the eclipse magnetic variation was a phenomenon similar to the diurnal variation, and that it differed from the latter only in degree; the ranges in the declination variations, for example, were proportional to the amounts of radiation cut off by the respective bodies: the moon and the earth.

It is known how a moving electrified particle will be deflected by a magnetic field, and how, in general, it will be made to travel in a spiral path whose axis is the line of magnetic force. Is it possible now, that as a result of the combined action of the permanent magnetic field of the rotating earth and the electrified particles radiated by the sun, there is formed in the regions above us a secondary magnetic system precisely similar to that of the earth?

The physical analysis of the permanent field, in addition to furnishing a number of interesting results, thus leads us, in a seductive manner, to the consideration of forces and phenomena not hitherto associated with those of the permanent magnetic field. We are led to inquire as to the rôle played, in the economy of nature, by the magnetic energy stored up in the regions outside, due to the earth's permanent magnetic field, in preventing certain solar radiations from reaching the lower

strata of our atmosphere. And at this threshold it will be well for us to pause and defer further exploration to a future time.

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SCIENTIFIC BOOKS.

Educational Psychology. By EDWARD L. THORNDIKE, adjunct professor of genetic psychology in Teachers College, Columbia University. New York, Lemcke and Buechner. 1903. 173 pp.

This book 'attempts to apply to a number of educational problems the methods of exact science' and to place at the service of students the incoherent mass of psychological knowledge which constitutes 'the beginnings of what we may call a general dynamic psychology.' That the facts already known "have thus far gone without systematic and convenient exposition is due to the complexity of the problems involved, not to any doubt concerning their practical importance. What we think and what we do about education is certainly influenced by our opinions about such matters as individual differences in children, inborn traits, heredity, sex differences, the specialization of mental abilities, their interrelations, the relation between them and physical endowments, normal mental growth, its periodicities, and the method of action and relative importance of various environmental influences." These then are the topics with which the book is concerned.

The first chapters deal with the measurement of mental traits. They explain the statistical principles by which we can apply exact measurements to groups of variable objects taken as a whole, and then proceed to show that in the matter of mental traits, as of physical, human beings of the same sex and approximately the same race, age and experience constitute a true group—that for every mental trait there is a mean or 'center of gravity' from which slight variations are frequent and great variations rare, according to the law of the distribution of chance events; so that measurements in terms of percentile grades or other relative standing can be interpreted fairly accurately in terms of absolute amount, and causal agencies acting unequally on different parts of the group can be detected by the analysis of curves of distribution.

In the fourth chapter the author explains the statistical principles by which we can measure the correlation between different characteristics in a group of individuals, and then applies Pearson's coefficient to show that in the matter of mental traits this correlation is amazingly small. This means that within a given group of individuals goodness or badness in one psychological function (as shown by school grades or the results of special tests) is not particularly likely to be accompanied by a similar amount of goodness or badness in another, even though the two appear to be only slightly different. If any one is disposed to deny this, let him first go over the large amount of evidence (much of it based on his own incessant investigations) which Dr. Thorndike puts together in this chapter.

Ever since the appearance of Professor James's chapter on memory the doctrine of general mental functions which can be cultivated by appropriate exercise and then turned to any use (a survival of the old 'faculty' psychology) has been more and more discredited amongst psychologists, though college presidents still make use of it to proclaim their wares and teachers in the public schools have never dreamed of anything else. But this doctrine can not be reconciled with the small coefficients of correlation shown in chapter IV. If there is such a thing as training or neglecting 'the memory' we should expect to find goodness or badness in remembering words accompanied by something like the same amount of goodness or badness in remembering numbers, to say nothing of colors, forms and tastes. But as a matter of fact the correlation is 'slight and variable'; and so with other functions.

In chapter VIII., on 'The Influence of Special Forms of Training upon More General Abilities,' the author presents evidence bearing still more directly upon this important educational doctrine, and gives a powerful argument to those who would adapt school